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PD1/7700 25.00 - 9804286.4

2. Patent application number
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9804286.4

27 FEB 1998

3. Full name, address and postcode of the
or of each applicant (underline all surnames)

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Patents ADP number (if you know it)

6996102001

If the applicant is a corporate body, give
country/state of incorporation

GB

4. Title of the invention

Time of Flight Mass Spectrometer and
Detector Therefor

5. Name of your agent (if you have one)

Frank B. Dehn & Co.

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to which all correspondence should be sent
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Patents ADP number (if you know it)

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67901.343

Time of Flight Mass Spectrometer and Detector Therefor

5 This invention relates to a time-of-flight mass spectrometer and its associated ion detection system. It provides apparatus for detecting ions in a time-of-flight mass spectrometer, and methods of operating that apparatus, which result in improved performance at a lower cost when compared with prior spectrometers.

10 In a time-of-flight mass spectrometer, a bunch of ions enters a field-free drift region with the same kinetic energy and the ions temporally separate according to their mass-to-charge ratios because they travel with
15 different velocities. Ions having different mass-to-charge ratios therefore arrive at a detector disposed at the distal end of the drift region at different times, and their mass-to-charge ratios are determined by measurement of their transit time through the drift
20 region.

Prior detectors for time-of-flight mass spectrometers comprise an ion-electron converter followed by an electron multiplying device. In some embodiments, ions
25 strike a surface of the multiplying device to release electrons and a separate converter is not provided. Because the detector must respond to ions leaving the whole exit aperture of the drift region, it is conventional to use one or more microchannel plate
30 electron multipliers as the multiplying device. A collector electrode is disposed to receive the electrons produced by the channelplates and means are provided to respond to the current flow so generated and produce an output signal. The chief difference between such a
35 detector and the similar device conventionally used with magnetic sector, quadrupole or quadrupole ion-trap spectrometers is the electronic signal processing, which

must produce signals indicative of the transit time of the ions as well as the number arriving in any particular time window (corresponding to one or more mass-to-charge ratios). This data must be generated and read out before the next bunch of ions can be admitted into the drift region, so that detector speed is an important determinant of the repetition rate, and hence the sensitivity, of the entire spectrometer.

The earliest detectors for time-of-flight spectrometers comprised a DC amplifier connected to the collector electrode and an analogue-to-digital converter (ADC) for digitizing the output of the amplifier. Usually, this arrangement was used with time-slice detection whereby the amplifier was gated to respond only to ions arriving within a certain time window (typically corresponding to one mass unit). The time window was moved (relative to the time of entrance of ions into the drift region) during repeated cycles of operation so that a complete mass spectrum was eventually recorded. An improvement involved the use of several amplifiers and ADC's arranged to simultaneously record a different time window. Nevertheless, many cycles of the spectrometer are still required to record a complete mass spectrum and the repetition rate of the spectrometer is severely limited by the time taken for the analogue-digital conversion in each cycle. Digital transient recorders (for example, as described in US patents 4,490,806, 5,428,357 and PCT applications WO94/28631 and WO95/00236) have been devised to efficiently process the digital data produced by the ADC, but, particularly in the case of time-of-flight mass analyzers for the analysis of organic compounds, these do not represent a cost-effective solution to the problem of achieving a high repetition rate.

An alternative detection system for time-of-flight mass

spectrometers is based on ion counting. In these methods, a signal due to a single ion impact on the detector is converted to a digital boolean value, "true" (which may be represented by a digital "1") in the case of an ion impact, or "false" (e.g, a digital "0") if there has been no ion impact. Various types of timers and/or counters are then employed to process the digital data produced. For example, a counter associated with a particular time window may be incremented whenever a signal is generated in that time window. Alternatively, the output of a timer, started when an ion bunch enters, may be stored in a memory array whenever the detector generates a "true" signal. The advantage of an ion-counting detector over an analogue detector is that variations in the output signal of the electron multiplier due to a single ion impact, which may be $\pm 50\%$ or more, are effectively eliminated because each signal above the noise threshold is treated identically. Further, an ion counting detector does not suffer from the additional noise inevitably produced by the ADC incorporated in an analogue detector system, and is also faster in operation. Consequently, the contribution of noise to the overall ion count is reduced and a more accurate ion count is achieved, particularly in the case of small numbers of ions. The disadvantage is that the digital signal representing an ion impact must be processed very quickly, before the next ion arrives at the detector, if that ion is to be detected. In practice, all detectors have a "deadtime" immediately following an ion impact, during which they cannot respond to an ion impact. This limits the number of ions which can be detected in a given time, so that a dynamic range of the detector is also limited. Corrections can be made to the detector output to compensate for the effects of deadtime (see, for example, Stephen, Zehnpfenning and Benninghoven, J. Vac. Sci. Technol. A, 1994 vol 12 (2) pp 405-410), and in co-

pending patent application GB 9801565.4 filed 23 January 1998, but even when such corrections are carried out the detector dynamic range still effectively reduces the performance of a time-of-flight mass spectrometer with such a detector.

An improved ion-counting detector for time-of-flight mass spectrometry has been described in general terms by Rockwood at the 1997 Pittsburgh Conference, Atlanta, GA (paper No 733), and is available commercially from Sensor Larsen-Davis as the "Simulpulse" detector. According to information published by Sensor Larson-Davis it comprises a large number of individual equal-area anodes, each of which is provided with a digital pulse generating circuit which is triggered by the arrival of an ion at its associated anode. The anodes are disposed in a wide-area detector so that they are all equally likely to be struck by an ion exiting from the drift region. Consequently, simultaneous (or near-simultaneous) ion strikes are most likely to occur on different electrodes and the effect of detector deadtime is greatly reduced. The data from each of the anodes is summed into an 8-bit digital word representative of the ion intensity at any particular time, and the value of that word and its associated time is stored in a digital memory. However, such a detector is obviously complicated and expensive to manufacture.

Multiple anode detectors have also been used in time-of-flight mass spectrometers for imaging the spatial distribution of ions leaving the drift region, usually in conjunction with imaging time-of-flight analyzers. Such position-sensitive detectors are taught by Cierjacks, Petkovic et al. in Nucl. Instrum. and Methods in Phys. Res., 1985 vol A238 pp 354-364, Kellogg in Rev. Sci. Instrum. 1987 vol 58 (1) pp 38-42 and in PCT application No WO87/00682. These detectors produce

signals indicative of the spatial co-ordinates of an ion impact and operate in a substantially different way FROM the multiple-anode "Simulpulse" detector. They are generally slow in operation and use analogue signal processing rather than the ion-counting principle employed in the present invention.

It is an object of the present invention to provide a time-of-flight mass spectrometer and a detector therefor, which has a greater dynamic range than most prior apparatus and which is cheaper to manufacture than prior spectrometers and detectors of equivalent performance. It is a further object to provide methods for operating such a spectrometer and detector.

In accordance with these objectives there is provided a time-of-flight mass spectrometer comprising an ion source for repetitively generating bunches of ions from a sample to be analyzed, ion accelerating means for causing at least some of the ions comprised in each of said bunches to enter a drift region along an axis with substantially the same component of kinetic energy along said axis, in which drift region they become separated in time according to their mass-to-charge ratios, ion detection means disposed to receive ions after they have passed through said drift region, means for determining the transit time of said ions through said drift region, and means for determining the number of ions having one or more selected transit times;

characterized in that:-

- a) said ion detection means comprises at least two collection electrodes, each of which has a different effective area, on which may impinge said ions or particles generated from said ions, each said collection electrode having associated therewith separate means for registering the

arrival of a said ion, each said collection electrode and its associated means for registering having a deadtime consequent upon an earlier ion arrival during which it cannot register another ion arrival; and

- 5 b) said means for determining the number of ions having one or more selected transit times comprises means for counting the number of ion arrivals which have been registered at a said selected transit
- 10 time at one or more electrodes including the largest of said collection electrodes for which the ion arrival rate at that selected transit time does not exceed a predetermined value above which the
- 15 presence of said deadtime would result in significant errors in the number of ion arrivals registered at that electrode.

In the above, the term "effective area" means the area of that part of a collector electrode on which the ions or other particles may impinge, corrected as necessary

20 for any lack of uniformity in the spatial distribution of ions incident on said ion detection means.

Preferably, the ion detection means further comprises charged-particle multiplying means which receives the

25 ions leaving the drift region and produces a burst of electrons in response to each ion arriving at the detection means. In such a case, the collection electrodes are disposed to receive these electrons. Typically, one or more channelplate electron multipliers

30 may be used. A separate conversion electrode, disposed to receive ions leaving the drift region and to generate secondary particles which then enter a particle multiplying means, may also be provided.

35 In preferred embodiments, said means for determining the number of ions having one or more selected transit times comprises means for counting the number of ion arrivals

which have been registered at:

- 1) The largest of said electrodes for which the arrival rate at that selected transit time does not exceed a predetermined value above which the presence of said
5 deadtime would result in significant errors in the numbers of ion arrivals registered at that electrode, and
- 2) At least one electrode smaller than that defined in
1) above, if present.

10

In preferred embodiments, the means for registering the arrival of an ion may comprise a fast discriminator which generates a digital "true" signal whenever the

15

voltage on its associated collector electrode rises above a pre-selected level in response to the arrival of charged particles on the electrode. Means for determining the transit time of ions through the drift region may comprise a multi-stop time digitizer which is started when a bunch of ions enters the drift region and
20 which generates a digital elapsed time signal in response to the generation of a "true" signal from the discriminators associated with the collection electrodes. The elapsed time signals may then be stored in a digital memory together with a flag indicative of
25 which collector electrode each signal is associated with.

30

In further preferred embodiments, two collector electrodes are provided, the larger one being between 2 and 20 times, and most preferably about 8 times, the area of the smaller.

35

Means for counting the ion arrivals registered at each of said selected transit times may comprise a suitably programmed digital computer. Conveniently, clock pulses corresponding to each of the selected transit times are generated and at each clock pulse each means for

registering an ion arrival is interrogated. In the case that an ion arrival is registered during a given clock pulse, the digital representation of the transit time from the time digitizer is stored in memory, together with a flag indicative of which electrode the arrival was at. The time digitizer may be reset on the generation of a new ion bunch so that the arrivals of ions in different bunches with a given mass-to-charge ratio are recorded with equivalent transit times.

Alternatively, the time at which each ion bunch is generated may be stored along with the ion arrival times so that actual transit times can be calculated later by subtraction of the start time of the ion bunch with which each arrival time is associated. At the end of a series of ion bunches, the total number of ions arriving at each of the collection electrodes at one or more (typically all) selected transit times may then be computed.

Digital computing means may also be used to estimate the ion arrival rate at each collection electrode and to establish whether or not it exceeds a predetermined value. Various methods of doing this are possible. In one preferred method, if the number of ion arrivals registered at the smallest electrode at each of said selected transit times is less than a predetermined value, then the ion arrival rate at the largest electrode at that transit time may be regarded as being sufficiently low to avoid deadtime problems.

Consequently, data from the larger electrode may be used to determine the number of ions having that selected transit time. However, if the number of ion arrivals at the smaller electrode exceeds the predetermined value, data associated with the larger electrode is likely to be inaccurate and the number of ions having that transit time should be determined from the data associated with the smaller electrode only. The predetermined value may

- be established by determining the ratio of the ion counts at both electrodes at different incident ion fluxes. This ratio will remain constant as the flux is increased up to the point at which deadtime effects begin to affect the data associated with the larger electrode. At that point, the ratio will become biased in favour of the smaller electrode and the predetermined value may be established accordingly.
- 10 Alternatively, the ion arrival rate may be estimated by implication from the ratio of the number of bunches in which an ion arrival is registered at a given transit time to the total number of ion bunches. Should this ratio exceed a predetermined value (established from a
- 15 consideration of the known detector deadtime relative to the frequency of the generation of the ion bunches), data associated with the largest electrode may be rejected and use should be made only of data associated with the next smaller electrode. The ion arrival rate at
- 20 the smaller electrode will obviously be less than that at the larger electrode (in proportion to the ratio of the effective areas of the electrodes), so that the loss of counts due to ions arriving during its deadtime will be correspondingly smaller. Count data associated with
- 25 the smaller electrode is then typically employed in preference to that associated with the larger electrode for subsequent transit times until the ion arrival rate at the larger electrode has fallen to an acceptable level. Care must be taken in the case of detectors
- 30 having extending deadtimes that the lack of ion counts due to complete saturation of the larger electrode is not mistaken for a reduction in the true ion arrival rate, typically by inspection of the count data of the smaller electrodes, which in these circumstances will
- 35 indicate ion arrivals while none are being registered at the larger electrode.

Another method of determining the ion arrival rate, and hence whether to reject data associated with the largest electrode, is to apply one of the prior deadtime correction algorithms to the data for the larger electrode, which will indicate whether or not there is likely to be a significant number of ion arrivals during periods of deadtime. This method has the advantage that more accurate counts can be obtained for an ion arrival rate which is not so high as to require a switch to data associated with a smaller electrode but is high enough to result in some losses due to deadtime. A further preferred embodiment comprises use of the method of ~~deadtime correction taught in co-pending GB patent~~ application 9801565.4, which requires that the raw count data from the largest electrode is first processed by conventional mass spectrometric data handling software to produce an uncorrected mass spectrum which is subsequently corrected for the effects of deadtime by means of a previously calculated look-up table. This method generates corrections based on the ion count rates and can easily be adapted to switch to use of the count data from a smaller electrode when that associated with the larger electrode becomes too high. In the method of that application, the data acquired is processed to produce at least one observed mass spectrum comprising data representing the number of ions having particular transit times, and to recognize in the mass spectrum portions of the data which correspond to mass peaks. The process determines from at least one of said portions of data an observed peak area and an observed mass centroid; uses a predetermined peak shape function characteristic of said time-of-flight mass spectrometer and selected according to said observed mass centroid, to determine from said observed mass centroid a distribution function indicative of the shape of said mass peak; and applies a correction to said observed mass centroid to obtain a value of said mass centroid

corrected for the effect of detector dead-time, said
correction being obtained from a predetermined
correction table which gives values of said correction
for different values of said distribution function and
5 said observed peak areas, said predetermined table
having been obtained by predicting the effect of said
detector dead-time on each of a plurality of simulated
mass peaks having said peak-shape functions for
appropriate ranges of said distribution functions and
10 peak areas.

The digital computing means is further programmed to
multiply the data associated with the smaller electrode
by a factor based on the ratio of the effective areas of
15 the electrodes to make the data associated with that
electrode comparable with that associated with the
larger electrode.

The invention extends the dynamic range of the
20 spectrometer because in prior single-collector electrode
spectrometers, the ion flux has to be limited to prevent
saturation of the detector, otherwise data is
irretrievably lost, even if prior methods of deadtime
correction are applied. In a spectrometer according to
25 the invention, the ion-flux can be increased beyond that
which would cause saturation of the largest collector,
thereby allowing low intensity peaks to be recorded
using data associated with the largest electrode, while
the most intense peaks may be recorded using data
30 associated with the smaller electrodes. A similar
result is achieved by the prior "Simulpulse" detector
discussed above, but the present invention, using
electrodes of different effective areas represents a
more cost-effective solution by reducing the number of
35 electrodes and their associated electronics. In the
invention, the dynamic range may be increased by
approximately a factor of 10 by the use of two

electrodes having a ratio of areas of 10:1 while a similar increase using the prior detector would require 10 electrodes of equal areas.

5 It will be appreciated that the invention is particularly valuable when the spectrometer comprises an ion source which is capable of producing intense ion beams at certain masses and far smaller ion beams at other masses, for example an inductively-coupled plasma
10 ion source or electron-impact, chemical ionization or APCI ion sources. However, other types of ion sources, for example electrospray or matrix-assisted laser desorption ion sources (MALDI) may also be employed.

15 Viewed from another aspect the invention provides a method of time-of-flight mass spectrometry comprising repetitively generating bunches of ions from a sample to be analyzed, accelerating at least some of the ions comprised in each of said bunches so that they have
20 substantially the same component of kinetic energy along an axis and allowing them to separate in time according to their mass-to-charge ratios during their subsequent passage through a drift region along said axis, detecting at least some of said ions after they have
25 passed through said drift region and determining for each of those ions so detected their transit times through said drift region, and determining the number of ions having one or more selected transit times, said method characterised in that:-

30 a) the step of detecting at least some of said ions comprises allowing said ions, or particles generated therefrom, to impinge on at least two collection electrodes of different effective areas, each of which having associated therewith separate
35 means for registering the arrival of a said ion, each said collection electrode and its associated

means for registering having a deadtime consequent upon an earlier ion arrival during which it cannot register another ion arrival; and

5 b) the step of determining the number of ions having
one or more selected transit times comprises
counting the number of ion arrivals registered at a
said selected transit time at one or more
electrodes including the largest of said collection
10 electrodes for which the ion arrival rate at that
selected transit time does not exceed a
predetermined value above which the presence of
said deadtime would result in a significant error
in the number of ions counted.

15 Preferred variations on the method will be apparent from the discussion presented above in respect of the apparatus of the invention.

20 An embodiment of the invention will now be described in greater detail by way of example only with reference to the figures, in which:-

figure 1 is a schematic drawing of an ICP mass spectrometer according to the invention;
figure 2 is a drawing of an ion detector suitable for use in the invention; and
figure 3 is a drawing of a collector electrode array suitable for use in the detector of figure 2.

30 Referring first to figure 1, an ICP mass spectrometer
according to the invention generally indicated by 1
comprises an ICP torch 2 which generates a plasma 3. As
in conventional ICP mass spectrometers a sample to be
35 analyzed may be introduced into the torch 2 entrained in
the torch gas supplies (not shown). Ions characteristic
of such a sample are generated in the plasma 3. The

torch 2 is disposed adjacent to a sampling cone 4 which comprises an orifice 5 through which at least some of the ions generated in the plasma 3 may enter a first evacuated chamber 6 which is pumped by a first pump 7.

5 In agreement with conventional practice there is provided a skimmer 8 which cooperates with the sampling cone 4 to provide a nozzle-skimmer interface. An additional stage of pumping is provided by a second pump 10 connected to a second evacuated chamber 9. Ions from the plasma 3 exit from the skimmer 8 along an axis 11, pass through the second evacuated chamber 9 and exit through a third evacuated chamber 13 through an orifice in a conical extraction lens 12 which forms part of the boundary wall between the chambers 9 and 13. The third
15 chamber 13 is evacuated by a third pump 14. In accordance with the teachings of EP patent application 0813228 a hexapole rod assembly 15 (containing gas at a pressure of about 10^{-2} torr) is provided in the third evacuated chamber 13 to reduce interferences from
20 unwanted species and reduce the energy spread of ions.

After passing through the rod assembly 15 ions pass through an orifice 16 in a wall 17 which divides the third evacuated chamber 13 from a fourth evacuated
25 chamber 18 which contains a time-of-flight mass analyzer. A vacuum pump 19 maintains the pressure in the chamber 18 at 10^{-6} torr or better. On entering the evacuated chamber 18 the ions pass through an electrostatic focusing lens 20 and enter an ion pusher
30 21, electrodes in which are fed with pulses from a pulse generator 22 in such a way that bunches of ions are repeatedly ejected parallel to an axis 25 into a drift region 24. In a general sense, therefore, items 1-24 comprise an ion source for repeatedly generating bunches
35 of ions. The ion pusher 21 comprises ion accelerating means for causing at least some of these bunches to enter the drift region with substantially the same

component of kinetic energy along the axis 25 (which is perpendicular to the ion axis 11). This arrangement therefore comprises an orthogonal acceleration time-of-flight analyzer, but a linear arrangement is also within the scope of the invention. The ions leaving the ion pusher 21 travel into the drift region 24 along a trajectory 23, (which deviates from the axis 25 because the ions have a finite component of velocity in the direction of the ion axis 11), and become separated in time according to their mass to charge ratios. The drift region 24 is a reflecting type analyzer and comprises an electrostatic ion mirror 26 which changes the direction of travel of the ions following trajectory 23 and directs them into an ion detector 27. Use of the ion mirror 26 both decreases the size of the spectrometer and improves mass resolution but a linear analyzer could be used if desired. Means for registering the arrival of a said ion comprises at least two fast discriminators 28 (one for each of the electrodes in the ion detector 27) and produces a digital signal each time an ion arrives at the detector 27. Means for determining the transit time of ions through the drift region 24, and means for determining the number of ions having one or more selected travel times comprise a clock generator 29 and a digital computer 30 and are described in more detail below.

Referring next to figure 2, an embodiment of the ion detector 27 suitable for use in the invention comprises first and second microchannel multiplier plates 31 and 32 disposed to receive ions directed towards the detector 27 by the ion mirror 26 (figure 1). This ion flux is schematically illustrated in figure 2 by the arrows 33. Each ion strikes the front surface of the first multiplier plate 31 causing the release of a burst of electrons at its rear surface at a point corresponding to the ion impact. These electrons are

received at the front face of the second multiplier plate 32 so that a larger burst of electrons is generated at its rear face. These impact on a collection electrode array 34 and the charge so transferred to one or more of the electrodes in the array is detected by the discriminators 28. A power supply 35 maintains potential differences between the faces of the multiplier plates 31 and 32, as required for their proper operation.

10

A preferred collection electrode array is illustrated in figure 3. It comprises an insulated substrate 37, typically of ceramic, on which are coated three electrically conductive electrodes 38, 39 and 36. Two of these, electrodes 38 and 36, are connected by the lead 41 and function as a single electrode of area approximately eight times that of the smaller electrode 39. This arrangement of electrodes compensates for an inhomogeneous distribution of the ion flux represented by the array 33, at least along an axis parallel to the long dimension of the electrode 39, but other arrangements of electrodes are within the scope of the invention.

25

It will be appreciated that the arrival of the ions at the detector 27 is random in space (in the absence of any instrumentally introduced inhomogeneity) so that the number of ion arrivals recorded at the composite larger electrode comprising electrodes 38 and 36 will be approximately eight times that recorded on the smaller electrode 39. In this invention the detector is not position sensitive and, given a homogeneous ion flux, the only significance of the pattern of the electrodes is the ratio of their areas. If, however, in any practical embodiment the ion flux is known to be inhomogeneous, the electrode pattern can be arranged to minimize its effect.

35

As explained above, although two electrodes are adequate for most purposes, it is also within the scope of the invention to use a greater number, each of which has a different area. Further, particularly in the event of inhomogeneity of the incident ion beam, the effective areas of the electrodes may not be exactly equivalent to their actual areas. The ratio of the effective areas may be easily established, however, by monitoring the signals from both electrodes while the detector is receiving a substantially constant ion flux, for example from a calibration compound introduced into the ion source. Care must be taken, however, that the ion intensity during the calibration process is not so great that the signal from the larger electrode is distorted by detector dead-time.

Each electrode comprised in the array is connected to a fast discriminator 28 which responds to the arrival of charge at an electrode by generating a digital signal comprising a flag and a time value obtained from a clock pulse generator 29 at the moment the arrival of charge is detected. A digital computer 30 stores this value so that the transit time of the ion which generated the signal can be determined. To facilitate this, the time at which the ion pusher 21 is activated by the pulse generator, thereby causing a bunch of ions to enter the drift region, is also stored by the computer 30. The transit time of each detected ion is determined merely by subtracting the appropriate time of entry of the ions into the drift region from the time at which the ion is detected, using a digital computer 30.

The computer 30 is programmed to determine the number of ions having one or more transit times as follows:-

First, the number of times an ion arrival is registered at each of the electrodes at each tick of the clock

pulse generator 29, is determined by inspection of the flagged transit time data, so that a histogram of ion counts against transit time (which corresponds to a mass spectrum uncorrected for dead-time) may be produced in respect of each electrode. In the event that only certain mass peaks need to be monitored, ion count data need only be retained at each of one or more selected transit times (i.e., clock ticks) corresponding to the mass-to-charge ratios to be monitored.

10

Next, the ion arrival rate at the smallest collection electrode 39 is compared with a predetermined value (typically established by experiment, as explained previously) to establish whether or not data from the composite largest electrode (38,36) is acceptable. If it is, the sum of the counts on both the largest electrode and the smallest electrode is used to determine the number of ions having that particular transit time. If the comparison indicates that data associated with the larger electrode is likely to be inaccurate, only data associated with the smaller electrode 39 is used, multiplied by a factor dependent on the ratio of the effective areas of the electrodes. This process is repeated for each of the selected transit times.

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An alternative method of estimating the ion arrival rate is the application of a prior method of deadtime corrections to the raw count data at each selected transit time, such as that discussed by Stephan (see above). The point at which the ion arrival rate becomes high enough for the significant deadtime corrections to be necessary will then be obvious from the results of the correction process. If corrections are applied to the count data then a higher predetermined value for the ion arrival rate can be used to trigger the switch to a smaller electrode because the corrections applied will

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result in more reliable data being produced for the larger electrodes at high arrival rates. However, use of most prior methods of deadtime correction incurs significant computing time, thereby reducing the repetition rate of the spectrometer, or requires storage of a large volume of data in high-speed memory. Another method of applying some deadtime correction is to process the uncorrected count data using conventional mass-spectrometric data processing software to recognise the mass peaks and produce a "stick" mass spectrum comprising values of ion intensity for each recognised mass peak using data obtained on one or more electrodes including the largest one. This data may then be corrected for deadtime according to the method of co-

pending GB patent application 9801565.4. This will indicate regions of the spectrum where the ion arrival rate is high enough to require only the use of data associated with the smaller electrode, and those portions of the spectrum may then be replaced by equivalent portions obtained by an identical treatment of the ion count data obtained on the smaller electrode, allowing for the ratio of the effective areas of the electrodes.

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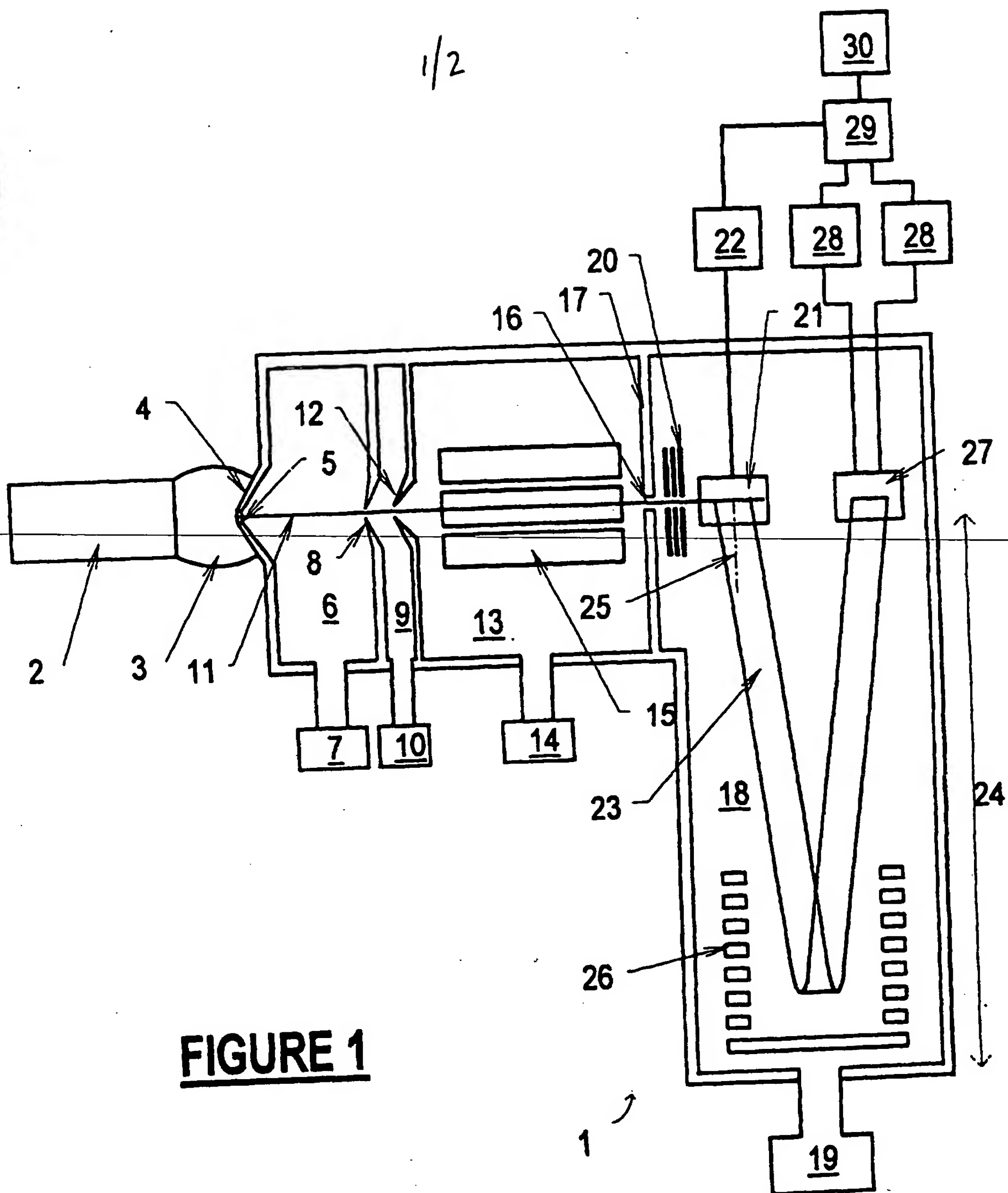


FIGURE 1

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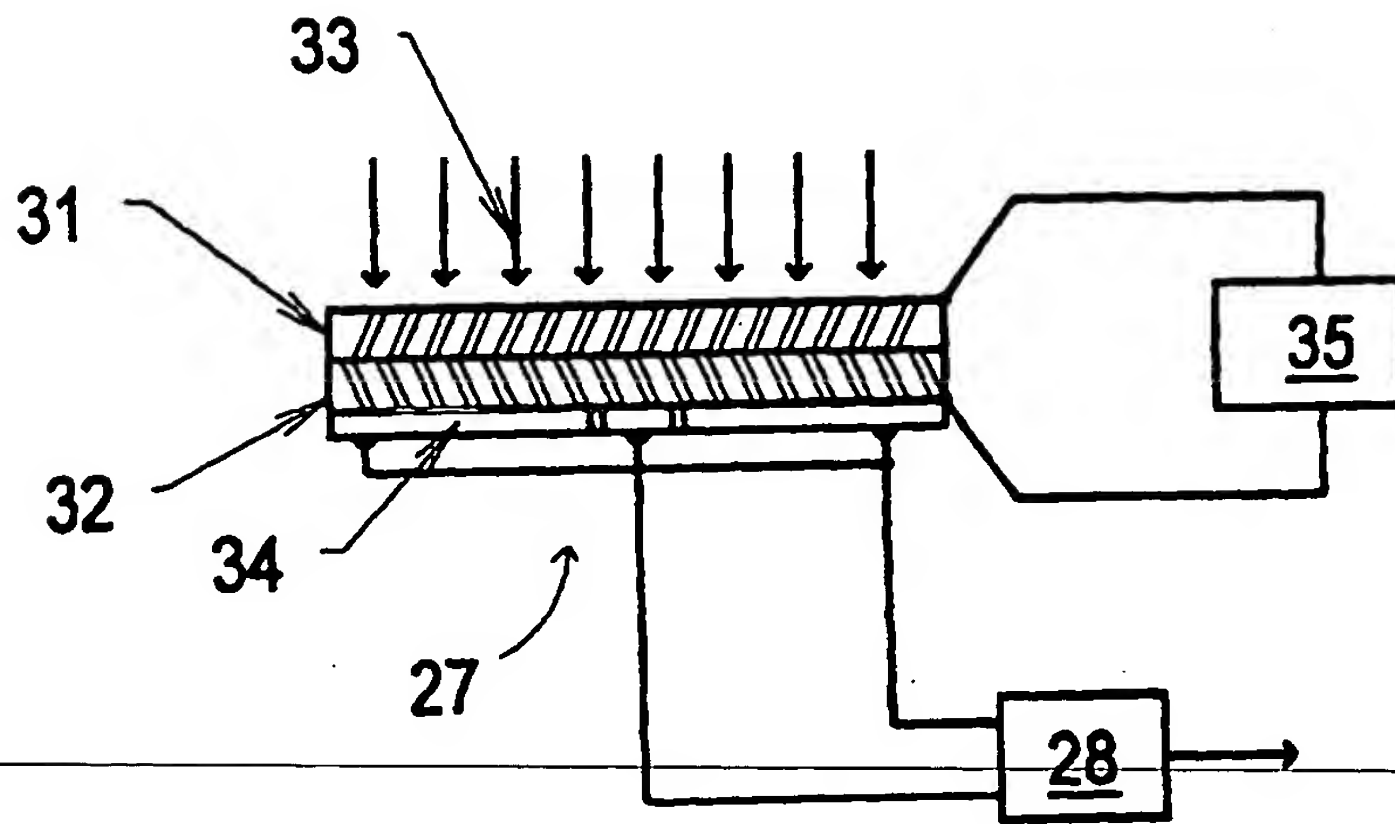


FIGURE 2

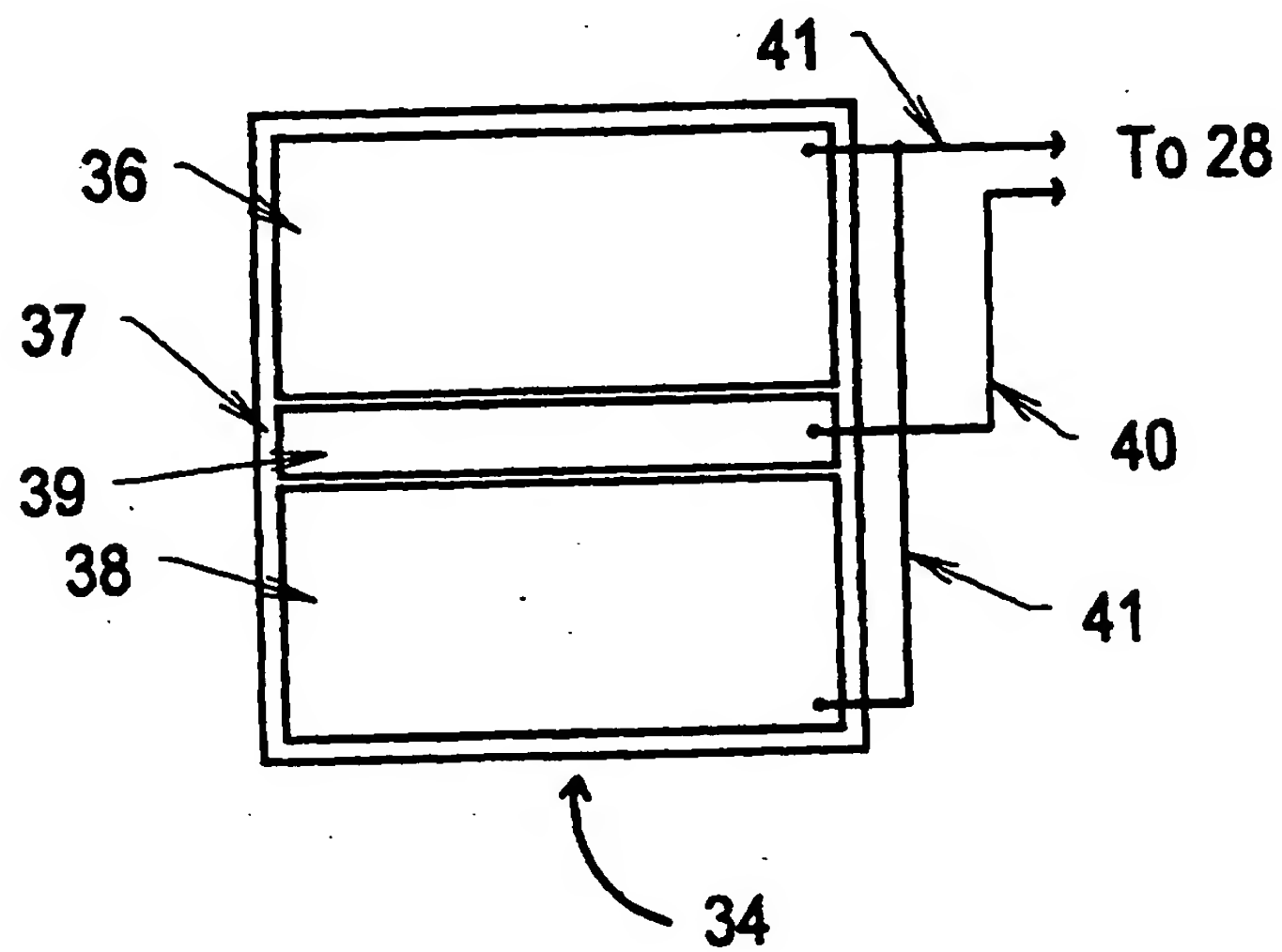


FIGURE 3



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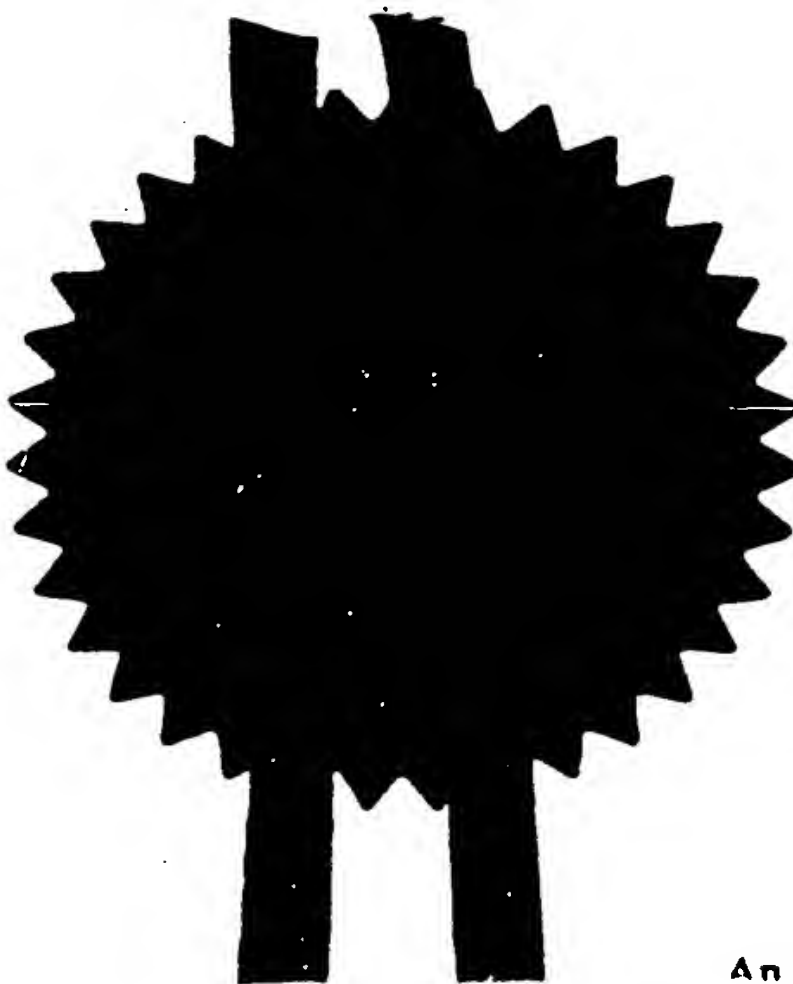
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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form.)

1. Reference	80.85.67901/002		
2. Patent application number (The Patent Office will fill in this part)	9813224.4		18 JUN 1998
3. Full name, address and postcode of the or of each applicant (underline all surnames)	Micromass Limited Floats Road, Wythenshawe, Manchester M23 9LZ, UK.		
Patents ADP number (if you know it)			
If the applicant is a corporate body, give country/state of incorporation	6996/02001		
4. Title of the invention	Time of flight mass spectrometer and dual gain detector therefor		
5. Name of your agent (if you have one)	Frank B. Dehn & Co.		
"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)	179 Queen Victoria Street London EC4V 4EL		
Patents ADP number (if you know it)	166001		
6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number	Country	Priority application number (if you know it)	Date of filing (day / month / year)
7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application	Date of filing (day / month / year)	
8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if: a) any applicant named in part 3 is not an inventor, or b) there is an inventor who is not named as an applicant, or c) any named applicant is a corporate body. See note (d))	Yes		

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Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

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Request for substantive examination (Patents Form 10/77)

Any other documents (please specify)

11. I/We request the grant of a patent on the basis of this application.

Signature K.J. Tomlinson Date 17 June 1998

12. Name and daytime telephone number of person to contact in the United Kingdom

K.J. Tomlinson
01273 244200

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67901002.344

TIME OF FLIGHT MASS SPECTROMETER AND DUAL GAIN DETECTOR
THEREFOR

10 This invention relates to a time-of-flight mass spectrometer and its associated ion detection system. It provides apparatus for detecting ions in a time-of-flight mass spectrometer, and methods of operating that apparatus, which result in improved performance at a lower cost when compared with prior spectrometers.

15 In a time-of-flight mass spectrometer, a bunch of ions enters a field-free drift region with the same kinetic energy and the ions temporally separate according to their mass-to-charge ratios because they travel with different velocities. Ions having different mass-to-charge ratios therefore arrive at a detector disposed at the distal end of the drift region at different times, and their mass-to-charge ratios are
20 determined by measurement of their transit time through the drift region.

Prior detectors for time-of-flight mass spectrometers comprise an ion-electron converter followed by an electron multiplying device. In some
25 embodiments, ions strike a surface of the multiplying device to release electrons and a separate converter is not provided. Because the detector must respond to ions leaving the whole exit aperture of the drift region, it is conventional to use one or more microchannel plate electron multipliers as the multiplying device. A
30 collector electrode is disposed to receive the electrons produced by the microchannel plates and means are provided to respond to the current flow so generated and produce an output signal. The chief difference between
35 such a detector and the similar device conventionally used with magnetic sector, quadrupole or quadrupole ion-trap spectrometers is the electronic signal processing, which must produce signals indicative of the transit

time of the ions as well as the number arriving in any particular time window (corresponding to one or more mass-to-charge ratios). This data must be generated and read out before the next bunch of ions can be admitted into the drift region, so that detector speed is an important determinant of the repetition rate, and hence the sensitivity, of the entire spectrometer.

The earliest detectors for time-of-flight spectrometers comprised a DC amplifier connected to the collector electrode and an analogue-to-digital converter (ADC) for digitizing the output of the amplifier. Usually, this arrangement was used with time-slice detection whereby the amplifier was gated to respond

only to ions arriving within a certain time window (typically corresponding to one mass unit). The time window was moved (relative to the time of entrance of ions into the drift region) during repeated cycles of operation so that a complete mass spectrum was eventually recorded. An improvement involved the use of several amplifiers and ADC's arranged to simultaneously record a different time window. Nevertheless, many cycles of the spectrometer are still required to record a complete mass spectrum and the repetition rate of the spectrometer is severely limited by the time taken for the analogue-digital conversion in each cycle. Digital transient recorders (for example, as described in US patents 4,490,806, 5,428,357 and PCT applications WO94/28631 and WO95/00236) have been devised to efficiently process the digital data produced by the ADC, but, particularly in the case of time-of-flight mass analyzers for the analysis of ions from continuous (as opposed to pulsed) ion sources, these do not represent a cost-effective solution to the problem of achieving a high repetition rate.

An alternative detection system for time-of-flight mass spectrometers is based on ion counting. In these methods, a signal due to a single ion impact on the detector is converted to a digital boolean value, "true"

(which may be represented by a digital "1") in the case of an ion impact, or "false" (e.g, a digital "0") if there has been no ion impact. Various types of timers and/or counters are then employed to process the digital data produced. For example, a counter associated with a particular time window may be incremented whenever a signal is generated in that time window. Alternatively, the output of a timer, started when an ion bunch enters, may be stored in a memory array whenever the detector generates a "true" signal. The advantage of an ion-counting detector over an analogue detector is that variations in the output signal of the electron multiplier due to a single ion impact, which may be $\pm 50\%$ or more, are effectively eliminated because each signal above the noise threshold is treated identically.

Further, an ion counting detector does not suffer from the additional noise inevitably produced by the ADC incorporated in an analogue detector system, and is also faster in operation. Consequently, the contribution of noise to the overall ion count is reduced and a more accurate ion count is achieved, particularly in the case of small numbers of ions. The disadvantage is that the digital signal representing an ion impact must be processed very quickly, before the next ion arrives at the detector, if that ion is to be detected. In practice, all detectors have a deadtime immediately following an ion impact, during which they cannot respond to an ion impact. This limits the number of ions which can be detected in a given time, so that a dynamic range of the detector is also limited.

Corrections can be made to the detector output to compensate for the effects of deadtime (see, for example, Stephen, Zehnpfenning and Benninghoven, J. Vac. Sci. Technol. A, 1994 vol 12 (2) pp 405-410), and in corresponding patent application GB 9801565.4 filed 23 January 1998, but even when such corrections are carried out the detector dynamic range still effectively reduces the performance of a time-of-flight mass spectrometer

with such a detector.

An improved ion-counting detector for time-of-flight mass spectrometry has been described in general terms by Rockwood at the 1997 Pittsburgh Conference, Atlanta, GA (paper No 733), and is available commercially from Sensar Larsen-Davis as the "Simulpulse" detector. According to information published by Sensar Larson-Davis it comprises a large number of individual equal-area anodes, each of which is provided with a digital pulse generating circuit which is triggered by the arrival of an ion at its associated anode. The anodes are disposed in a wide-area detector so that they are all equally likely to be struck by an ion exiting from the drift region. Consequently, simultaneous (or near-simultaneous) ion strikes are most likely to occur on different electrodes and the effect of detector deadtime is greatly reduced. The data from each of the anodes is summed into an 8-bit digital word representative of the ion intensity at any particular time, and the value of that word and its associated time is stored in a digital memory. However, such a detector is obviously complicated and expensive to manufacture.

An electron multiplier ion detector for a scanning mass spectrometer which has two modes of operation to extend its dynamic range is disclosed by Kristo and Enke in Rev. Sci. Instrum. 1988 vol 59 (3) pp 438-442. This detector comprises two channel type electron multipliers in series together with an intermediate anode. The intermediate anode was arranged to intercept approximately 90% of the electrons leaving the first multiplier and to allow the remainder to enter the second multiplier. An analogue amplifier was connected to the intermediate anode and a discriminator and pulse counter connected to an electrode disposed to receive electrons leaving the second multiplier. The outputs of the analogue amplifier and pulse counter were electronically combined. A protection grid was also disposed between the multipliers. At high incident ion

fluxes, the output signal comprised the output of the analogue amplifier connected to the intermediate anode. Under these conditions a potential was applied to the protection grid to prevent electrons entering the second multiplier (which might otherwise cause damage to the second multiplier). At low ion fluxes, the potential on the protecting grid was turned off and the output signal comprised the output of the pulse counter. In this mode the detector operated in the single ion counting mode.

10 In this way the detector was operable in a low sensitivity analogue mode using the intermediate anode and a high sensitivity ion counting mode using both multipliers and the pulse counter, so that the dynamic

range was considerably greater than a conventional detector which use only one of these modes.

15 Other prior art teaching of electron multipliers with means for extending the dynamic range includes a simultaneous mode (i.e., pulse counting and analogue) electron multiplier taught in US Patent 5,463,219. US
20 Patent 4,691,160 teaches a discrete dynode electron multiplier having two final collector electrodes of different areas, each connected to a separate analogue amplifier and selectable by means of a manually operated switch. Soviet Inventors Certificate SU 851549 teaches
25 the disposition of a control grid between two channelplate electron multipliers, the potential on which can be adjusted to control the gain of the assembly. GB patent application 2300513 A teaches a similar control grid disposed between certain dynode
30 sheets in an electron multiplier comprising a stack of such sheets, and which is especially suitable for a photomultiplier tube. Prior art disclosed in US Patent 4,691,160 also comprises a continuous dynode electron
35 multiplier having two collector electrodes, one of which is capable of receiving electrons from a dynode disposed prior to the final dynode so that the multiplier has less gain.

Our corresponding GB patent application number

9804286.4 teaches a time-of-flight mass spectrometer having an ion-counting channelplate detector with two or more collection electrodes of unequal areas and means for automatically selecting data from the most appropriate electrode according to the ion flux at different mass to charge ratios. In this way the dynamic range of the detector is extended by switching to data from a smaller electrode whenever the data from a larger electrode is likely to be inaccurate due to detector deadtime.

It is an object of the present invention to provide a time-of-flight mass spectrometer and a detector therefor, which has a greater dynamic range than most prior apparatus and which is cheaper to manufacture than prior spectrometers and detectors of equivalent performance. It is a further object to provide methods for operating such a spectrometer and detector.

In accordance with these objectives there is provided a time-of-flight mass spectrometer comprising an ion source for repetitively generating bunches of ions from a sample to be analyzed, ion accelerating means for causing at least some of the ions comprised in each of said bunches to enter a drift region along an axis with substantially the same component of kinetic energy along said axis, in which drift region they become separated in time according to their mass-to-charge ratios, and an ion detector disposed to receive ions after they have passed through said drift region,

characterized in that:

- (a) said ion detector comprises electron multiplying means for producing secondary electrons in response to an ion entering said ion detector, a first collection electrode for receiving some of said secondary electrons, a second collection electrode for receiving others of said secondary electrons or other electrons derived from those electrons, said

second collection electrode receiving more electrons in response to said ion entering said ion detector than does said first collection electrode and each said collection electrode having associated therewith a separate signal processing means which has a digital output;

(b) digital memory means are provided for storing the digital outputs of each of said signal processing means at one or more transit times of said ions through said drift region relative to the generation of a said bunch of ions;

(c) output means are provided for accessing the data stored in said memory means after all the ions of interest generated in one or more of said bunches have entered said ion detector and retrospectively determining the quantity of ions which entered said ion detector at one or more of said transit times while said ion bunches were being generated.

In a preferred embodiment a second electron multiplying means may be provided between first collection electrode and the second collection electrode to receive electrons which are not collected on the first collection electrode and to generate a greater number of electrons per ion entering the detector at the second collection electrode than at the first collection electrode. Alternatively, both collection electrodes can be disposed to receive secondary electrons from a single electron multiplying means but the first electrode may have a smaller effective area than the second collection electrode so that the second collection electrode receives more electrons per ion entering the detector. The term "effective area" means that area of a collection electrode which actually receives the secondary electrons. Thus the first collection electrode may comprise a grid-like electrode of smaller effective area than the second collection electrode.

The signal processing means associated with each of

the collection electrodes may comprise an analogue or a digital (i.e, pulse-counting) system. Analogue signal processing means may comprise a fast analogue amplifier followed by an A-D converter which outputs a digital signal to the memory means on receipt of a clock pulse. Pulse-counting signal processing means may comprise a discriminator which generates a digital "true" signal to the memory means in response to the arrival of secondary electrons at the collection electrode in the period immediately preceding a clock pulse. Typically, a digital signal processing means is used in association with the second collection electrode to provide the maximum sensitivity. A pulse-counting system of this

nature unavoidably suffers from dead-time such that immediately following triggering of the discriminator and our corresponding patent application numbers GB 9804286.4 and GB 9810867.3 teach apparatus and methods for minimizing this problem in a similar detector system for a time-of-flight mass spectrometer.

Preferred embodiment of the memory means of the invention may comprise RAM associated with a suitably programmed digital computer or microprocessor. Thus, a spectrometer cycle is started each time a bunch of ions enters the drift region. In the case of an analogue signal processing means, a clock generator may cause the signal processing means to store the digital output of signal processing means in the memory means at a series of transit times corresponding to the ticks of the clock generator during that spectrometer cycle. After all the ions of interest have travelled through the drift region the spectrometer cycle is terminated, a new bunch of ions is generated and a new cycle is started. Data at each clock tick from this and subsequent cycles may then be added to the data previously stored in the memory means for the same transit time value. In the case of a pulse-counting detector a similar arrangement may be adopted, storing for example, a digital "1" at the clock tick immediately following the triggering of

the fast discriminator by an ion arrival at the associated collection electrode and accumulating valves at corresponding transit times in subsequent detector cycles. Alternatively, memory may be conserved by storing only each transit time at which an ion triggers the fast discriminator.

10 In accordance with the invention the output means is operative to determine the quantity of ions entering the detector at one or more transit times subsequent to the completion of at least one, and more usually many, spectrometer cycles. The number of cycles during which acquisition takes place will be dependent on the rate at which the mass spectrum is changing and the capacity of

15 the memory means. For example, in the case of a TOF spectrometer used for monitoring fast chromatographic peaks the repetition rate may be 10kHz and data may be stored for about 0.5 seconds (ie, approximately 5,000 spectrometer cycles) in the memory means before being processed by the output means. Longer time periods and

20 lower repetition rates are more typical for MALDI TOF spectrometers.

Once the data from the desired number of spectrometer cycles has been acquired, the output means may generate mass spectral data in the form of the

25 quantity of ions entering the detector at each of one or more transit times. The output means preferably uses the data associated with the second collection electrode (or the data associated with both the first and second collection electrodes) in order to obtain the maximum sensitivity. However, data associated with the second

30 electrode may be unreliable at certain transit times if the number of ions entering the detector at a particular transit time exceeds a certain limit, for example because of detector dead-time in the case of pulse-counting signal processing means or because of

35 saturation of the A-D converter in an analogue signal processing means. In such circumstances the output means may use data from the first collection electrode alone,

which data is less likely to suffer from deadtime or saturation problems. Conveniently, a decision on whether data from the second collection electrode is reliable at any given transit time is made from an examination of the data from the first collection electrode which has been stored in the memory means at the relevant transit time. The relative gains of the detector system of the collection electrodes and their associated signal processing means is known (either by experimental calibration or from the ratio of the areas of different sized collection electrodes) so that a threshold output level may be set in relation to the output of the signal processing means associated with the first collection electrode above which data associated with the second collection electrode should not be used. Preferably the output means comprises a suitably programmed digital computer.

Viewed from another aspect the invention provides a method of time-of-flight mass spectrometry comprising repetitively generating bunches of ions from a sample to be analyzed, accelerating at least some of the ions comprised in said bunches so that they have substantially the same kinetic energy along an axis and allowing them to separate in time according to their mass-to-charge ratios during their subsequent passage through a drift region along said axis, and detecting with an ion detector said ions after they have passed through said drift region, said method characterized in that:-

- (a) the step of detecting said ions comprises generating a plurality of secondary electrons from at least some of the ions entering said ion detector, collecting some of said secondary electrons on a first collection electrode, collecting others of said secondary electrons (or electrons derived from these electrons) on a second collection electrode, whereby said second

collection electrode receives more electrons per ion entering said detector than does said first collection electrode and separately generating digital signals representative of the number of electrons arriving at each said collection electrode;

- (b) storing said digital signals in digital memory means at one or more transit times of said ions through said drift region relative to the generation of a said bunch of ions;
- 10 (c) after all of the ions of interest generated in one or more of said bunches have travelled through said drift region, accessing the data stored in said digital memory means and retrospectively
- 15 determining the quantity of ions which were detected at one or more of said transit times while said ion bunches were being generated.

It will be appreciated that according to the invention and in contrast to the prior art of US 5463219

20 it is not necessary to provide fast hardware to examine the signals generated by the first collection electrode while the data is being acquired. Instead, the decision as to whether data associated with the second collection electrode is valid is made once all the data from a

25 plurality of ion bunches has been stored in the memory means. Consequently the speed at which data from the collection electrodes can be stored in the memory means is increased. This is especially important in the case of a time-of-flight spectrometer if the rate of

30 generation of ion bunches, and hence the sensitivity of the spectrometer, is not to be degraded. Prior types of dual mode electron multipliers (e.g, that described in US 5463219) intended for scanning mass spectrometers require hardware for monitoring the low-gain output

35 signal in order to activate some means of preventing damage to the high-gain section of the multiplier when the ion beam flux exceeds a certain value. However, with a time-of-flight spectrometer this situation does

not arise so readily because the number of ions arriving in each bunch will generally be far less than the number likely to cause damage to the multiplier. These prior types of dual-mode multipliers are unsuited to use with a time-of-flight mass spectrometer because the presence of the protection system reduces the rate of data acquisition. The present inventors have realized that the limitation on dynamic range in the case of a time-of-flight detector is more likely to be imposed by the limited dynamic range of a sufficiently fast A-D converter, or the dead-time of a pulse-counting system, and not by the possibility of saturation of or damage to the multiplier itself. Thus, the present invention

overcomes the limitations of prior dual-mode detectors when used for time-of-flight mass spectroscopy by storing data from the collection electrodes directly in the memory means and requiring no additional real-time processing or slow electronic hardware, and therefore, provides a detector with extended dynamic range which does not require the repetition rate of the spectrometer to be reduced.

Preferred variations on the method will be apparent from the discussion presented above in respect of the apparatus of the invention.

An embodiment of the invention will now be described in greater detail by way of example only with reference to the figures, in which:-

Figure 1 is a schematic drawing of an ICP mass spectrometer according to the invention;

Figure 2 is a drawing of an ion detector suitable for use in the invention;

Figure 3 is a drawing of an array of collection electrodes suitable for use in the detector shown in figure 2; and

Figure 4 is a drawing of an alternative type of ion detector suitable for use in the invention.

Referring first to figure 1, an ICP mass spectrometer according to the invention generally

indicated by 1 comprises an ICP torch 2 which generates a plasma 3. As in conventional ICP mass spectrometers a sample to be analyzed may be introduced into the torch 2 entrained in the torch gas supplies (not shown). Ions characteristic of such a sample are generated in the plasma 3. The torch 2 is disposed adjacent to a sampling cone 4 which comprises an orifice 5 through which at least some of the ions generated in the plasma 3 may enter a first evacuated chamber 6 which is pumped by a first pump 7. In agreement with conventional practice there is provided a skimmer 8 which cooperates with the sampling cone 4 to provide a nozzle-skimmer interface. An additional stage of pumping is provided by a second pump 10 connected to a second evacuated chamber 9. Ions from the plasma 3 exit from the skimmer 8 along an axis 11, pass through the second evacuated chamber 9 and exit through a third evacuated chamber 13 through an orifice in a conical extraction lens 12 which forms part of the boundary wall between the chambers 9 and 13. The third chamber 13 is evacuated by a third pump 14. In accordance with the teachings of EP patent application 0813228 a hexapole rod assembly 15 (containing gas at a pressure of about 10^{-2} torr) is provided in the third evacuated chamber 13 to reduce interferences from unwanted species and reduce the energy spread of ions.

After passing through the rod assembly 15 ions pass through an orifice 16 in a wall 17 which divides the third evacuated chamber 13 from a fourth evacuated chamber 18 which contains a time-of-flight mass analyzer. A vacuum pump 19 maintains the pressure in the chamber 18 at 10^{-6} torr or better. On entering the evacuated chamber 18 the ions pass through an electrostatic focusing lens 20 and enter an ion pusher 21, electrodes in which are fed with pulses from a pulse generator 22 in such a way that bunches of ions are repeatedly ejected parallel to an axis 25 into a drift region 24. In a general sense, therefore, items 1-24

comprise an ion source for repeatedly generating bunches of ions. The ion pusher 21 comprises ion accelerating means for causing at least some of these bunches to enter the drift region with substantially the same component of kinetic energy along the axis 25 (which is perpendicular to the ion axis 11). This arrangement therefore comprises an orthogonal acceleration time-of-flight analyzer, but a linear arrangement is also within the scope of the invention. The ions leaving the ion pusher 21 travel into the drift region 24 along a trajectory 23, (which deviates from the axis 25 because the ions have a finite component of velocity in the direction of the ion axis 11), and become separated in

time according to their mass to charge ratios. The drift region 24 is a reflecting type analyzer and comprises an electrostatic ion mirror 26 which changes the direction of travel of the ions following trajectory 23 and directs them into an ion detector 27. Use of the ion mirror 26 both decreases the size of the spectrometer and improves mass resolution but a linear analyzer could be used if desired.

Signal processing means 28 and 29 are connected to the collection electrodes in the detector 27 (described below) and their digital outputs are connected to a digital memory means 30. A digital computer 31 controls the signal processing means 28 and 29 and also the pulse generator 22 which controls the generation of ion bunches. Computer 30 is programmed to cause the pulse generator 22 to repetitively generate bunches of ions and to record the data generated by the signal processing means 28 and 29 for each bunch in the digital memory means 30, which typically comprises fast RAM. In the case of an analogue signal processing means, the digital output is recorded at a series of transit times relative to the time of generation of the ion bunch until all the ions of interest have entered the detector.

For maximum economy of memory usage a portion of

memory is set aside for storing the digital output at each of the series of transit times for one ion bunch. The values of the digital output at transit times for subsequent ion bunches are then added to the previously stored values at corresponding transit times in order to produce an averaged value at each transit time taken over the whole series of ion bunches. In the case of pulse-counting signal processing means, computer 30 is programmed to store the time at which an ion bunch is generated and the times at which ion arrivals at the detector triggers the signal processing means, which typically occurs only once for each ion bunch. This is more efficient than storing a boolean value representing

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the output of a pulse-counting system at each of the transit times at which the output of an analogue signal processing means has to be sampled, but the latter method is within the scope of the invention.

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During this data acquisition phase the computer 31 merely causes data to be stored in the memory means 30, and does not need to examine that data in any way. Similarly, no additional hardware responsive to the output of the signal processing means is required for the proper operation of the detector 27.

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Once the data from a desired number of ion bunches has been stored in the memory means, the digital computer 31 may access this data and copy it to a disk for subsequent processing, or may carry out that processing in real time, thereby freeing the digital memory 30 to receive data from the next series of ion bunches. During the subsequent processing the computer 31 determines the quantity of ions which entered the detector at each transit time while the ion bunches were generated using the data associated with the second collection electrode, except as provided for below. Computer 31 further applies tests to the data to establish whether data from the second collection electrode is valid, and if not, uses data from the first collection electrode alone. Various tests can be

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applied, for example in the case where signal processing means associated with the first collection electrode comprises an analogue amplifier and an A-D converter, if the signal from that electrode at any given transit time exceeds a certain predetermined value then it is certain that data associated with the second collection electrode will be unreliable, either because of deadtime problems in the case of an pulse counting system or saturation of the A-D converter in the case of an analogue system. When data from the first collection electrode is used it is multiplied by a factor equal to the ratio of the effective areas (defined above) of the collection electrodes to make it compatible with that from the second collection electrode. More elaborate tests, including deadtime correction in the case of ion-counting signal processing means, may be used if desired (see, for example, co-pending patent application GB9810867.3).

Referring next to figure 2, an embodiment of an ion detector suitable for use in the invention comprises a pair of microchannel plate electron multipliers 42, 32 disposed to receive ions directed towards the detector 27 by the ion mirror 26 (figure 1). The ion flux is schematically illustrated in figure 2 by the arrows 33. Each ion strikes the front surface of the multiplier plate 42 causing the release of a burst of electrons at its rear surface corresponding to the ion impact. These electrons are received by the front face of the second multiplier plate 32 so that a larger burst of electrons is generated at its rear face. These impact on a collection electrode array 34 and cause signals to be generated by the signal processing means 28, 29 which are connected to the electrodes in the array 34. A power supply 35 maintains a potential difference of approximately 2kV between the faces of the multiplier plates 42 and 32 as required for their proper operation. A collection electrode array 34 suitable for use in the detector illustrated in figure 2 is shown in figure 3.

It comprises an insulated substrate 37, typically of ceramic, on which are coated three electrically conductive electrodes 36, 38, and 39. Two of these electrodes, 36 and 38, are connected by the lead 41 and function as a single electrode of area approximately 8 times that of the smaller electrode 39. Lead 41 also connects the larger (second) composite electrode 36,38 to a signal processing means 28, and the lead 40 connects the smaller (first) electrode to a signal processing means 29. This arrangement of electrodes compensates for an inhomogeneous distribution of ion flux represented by the arrows 33, at least along an axis parallel to the long dimension of the electrode 39, but other arrangements of electrodes are within the scope of the invention.

An alternative embodiment of an ion detector 27 suitable for use with the invention is shown in figure 4. It comprises first and second electron multiplying means 43, 44, each of which comprises a microchannel plate electron multiplier. The channelplates are spaced apart by a series of insulators 45 which also supports a first collection electrode 46. Electrode 46 comprises a grid having a transparency of about 50% so that it collects approximately half of the electrons leaving the first multiplying means 43 and transmits the remainder to the second electron multiplying means 44. A second collection electrode 47 is disposed to receive electrons leaving the second electron multiplying means 44. Power supplies 48 and 49 maintain a potential difference of about 1kV across each of the channelplates. A third power supply 50 maintains a potential difference of about 200 volts between the rear face of channelplate 43 and the front face of channelplate 44 to ensure electrons are efficiently transmitted between the two. As in the figure 2 embodiment, signal processing means 28 and 29 are connected to the first and second collection electrodes 46 and 47 respectively. In a detector of this type, low-gain signals and high-gain

signals are available at the collection electrodes 46 and 47 respectively. These signals correspond to the signals at the small and large area collection electrodes 39 and 36,38 of the detector shown in figure

5 2.

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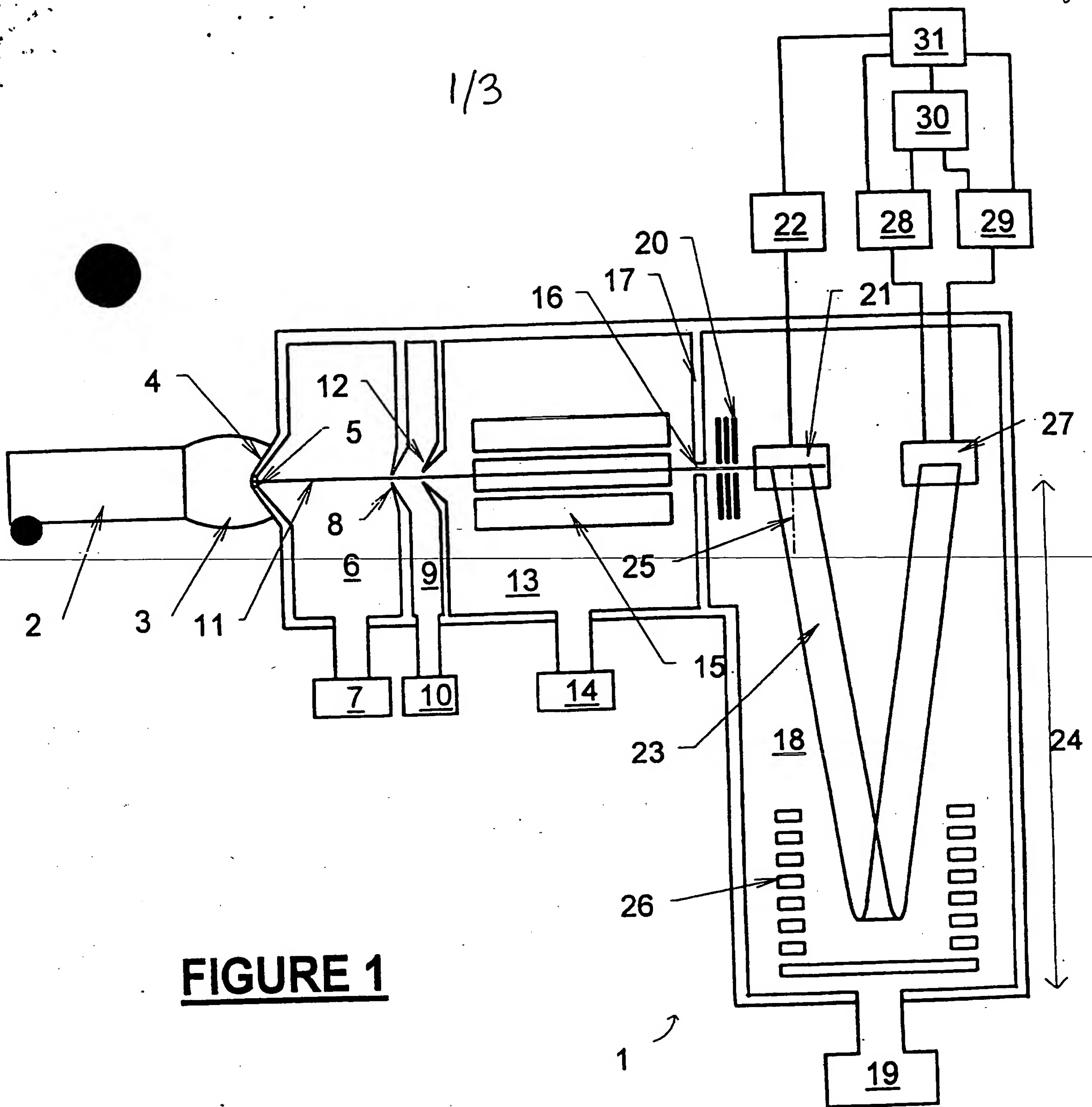


FIGURE 1

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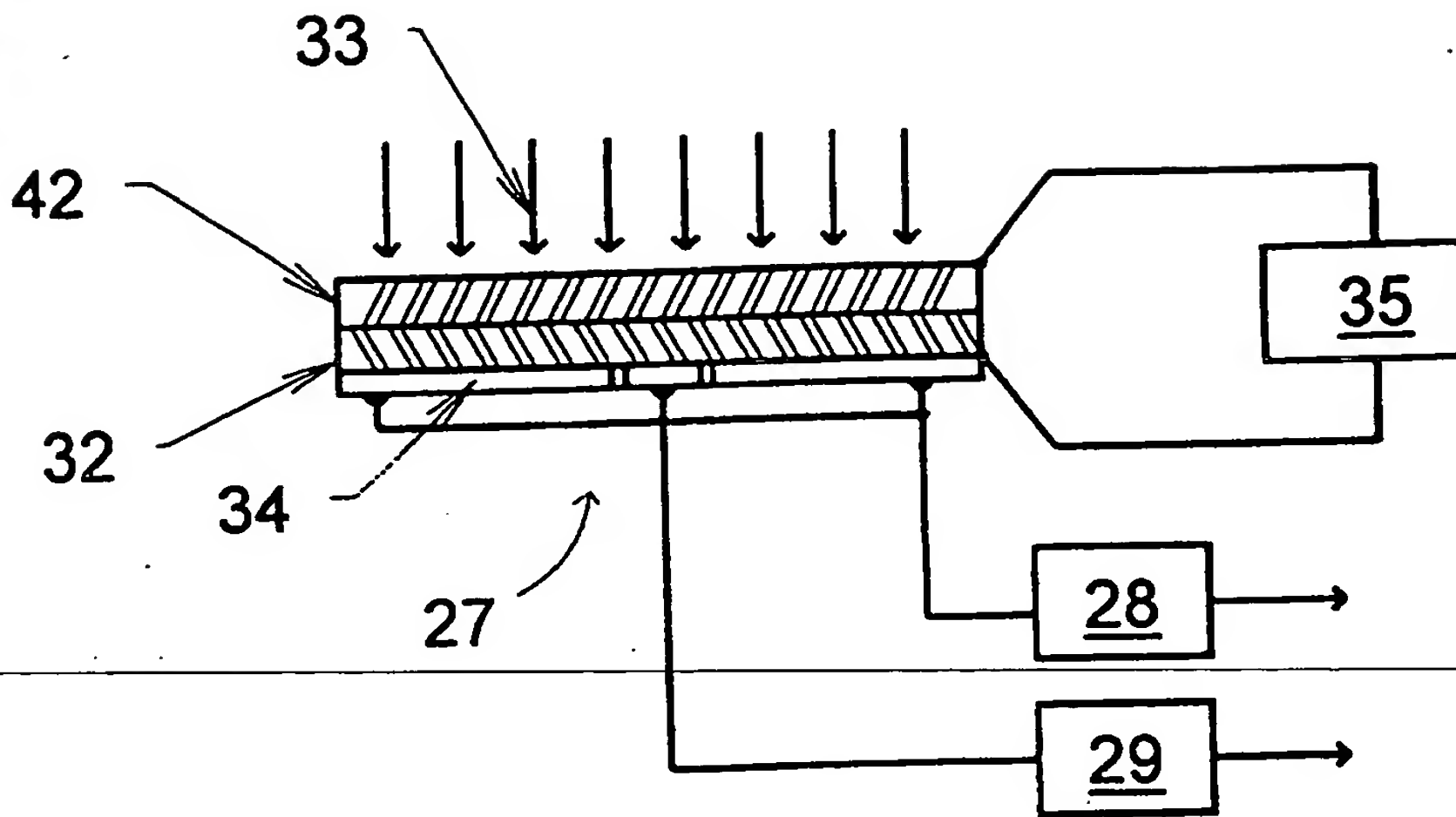


FIGURE 2

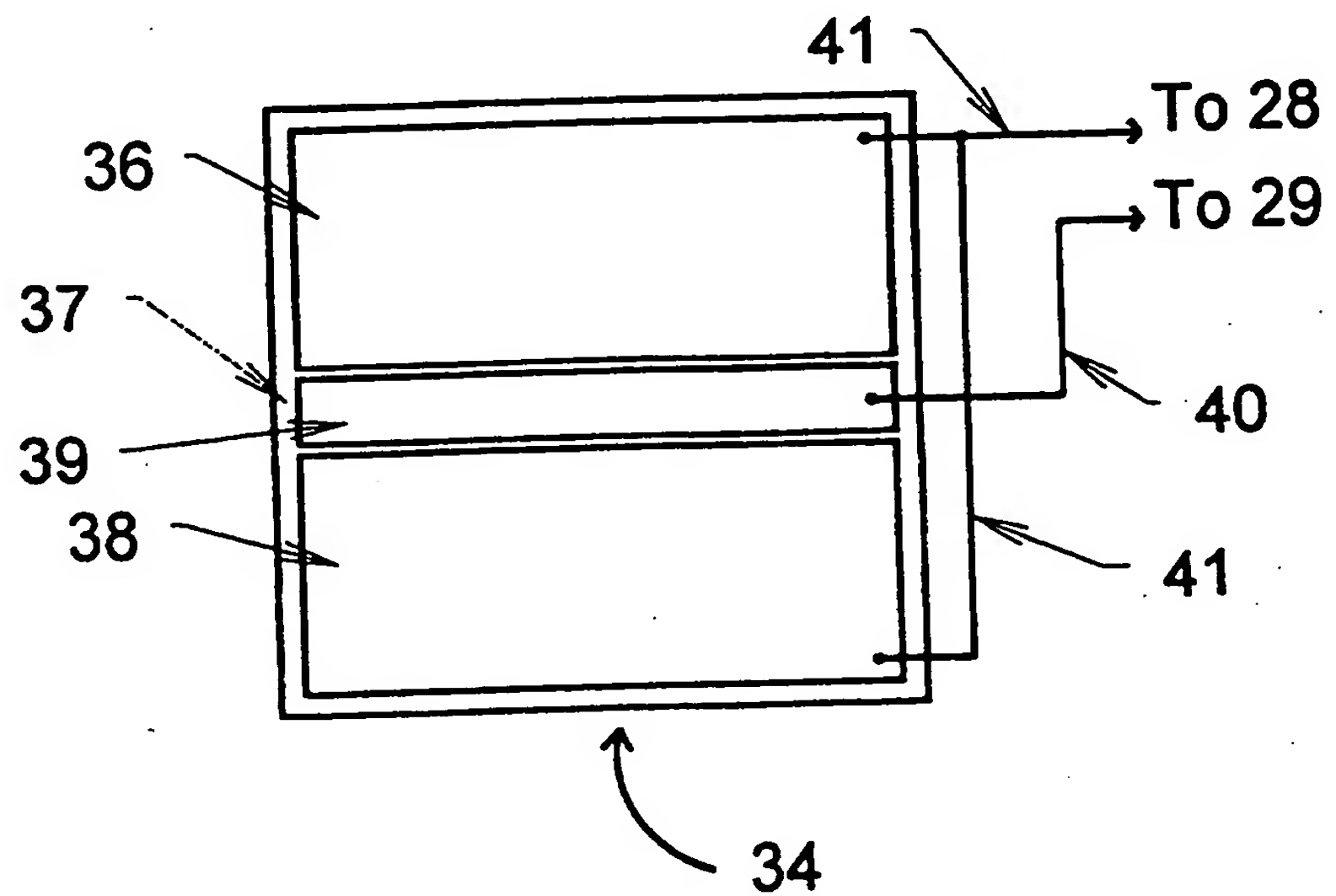


FIGURE 3

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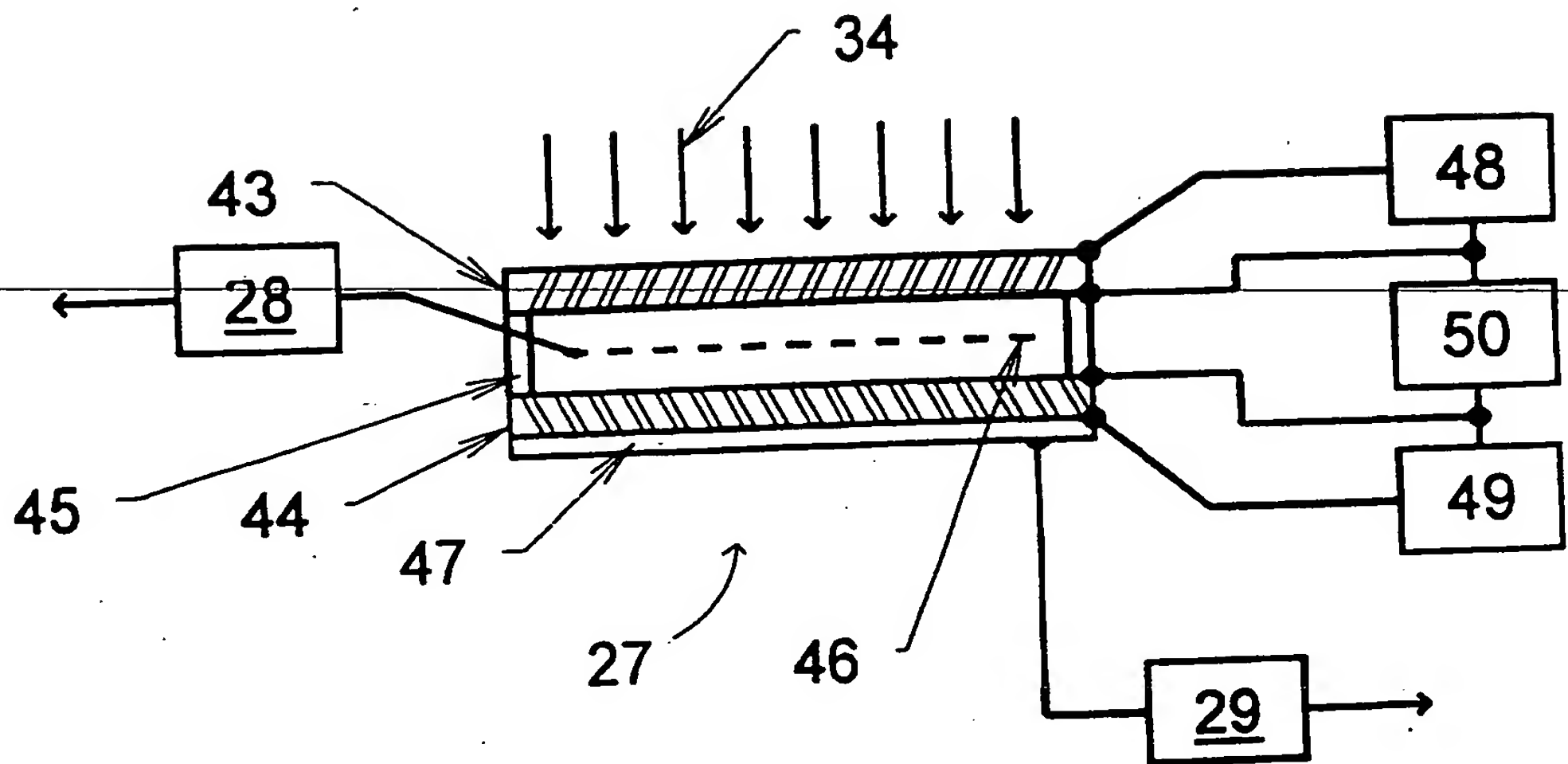


FIGURE 4